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A NEW METHODOLOGY FOR THE USE OF CORS TECHNIQUE IN THE FORESTED AREAS

SUMMARY

In forested areas, determining precise coordinates is difficult because dense vegetation and multi-path effects block Global Navigation Satellite System (GNSS) signals. This study proposes a new method to obtain coordinates without making direct GNSS measurements at the point of interest in the forest. Instead, the coordinates of the desired point are calculated theoretically using auxiliary points created in open areas. The positions of the auxiliary points are determined using Continuously Operating Reference Station (CORS)-based measurements. In this context, studies were carried out in two different test fields with different geometric configurations on the Davutpaşa campus of Yıldız Technical University. The point coordinates obtained from static, rapid static and CORS-based GNSS methods were compared with the reference coordinates obtained from total station measurements. The results showed that static GNSS provided the highest accuracy with the lowest deviation values from the reference data, while CORS had the lowest accuracy. However, all GNSS-based methods provided an accuracy of 10-15 cm, which was considered an acceptable level for forestry applications in this study. The accuracy of theoretical coordinates was affected by the geometric structure of the auxiliary points and the γ-angle between the two measurement lines. Namely, it leads to higher errors at small angles and around 200g angles. The proposed method provides a practical and efficient alternative for positioning in forested areas, reducing the long measurement times caused by GNSS signal occlusions, while maintaining sufficient accuracy for forestry and land surveying applications.

Keywords: CORS, multipath, forested area, coordinate computation, sine theorem

INTRODUCTION

The forestry industry's primary objective is the efficient utilization of forest resources. The meticulous planning and robust management strategies that underpin the monitoring and utilization of these resources are of paramount

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importance. In this context, the Global Navigation Satellite System (GNSS) plays a pivotal role, finding application in a variety of domains including forest road construction, damage monitoring in the context of illegal settlements or fires, forest harvesting and pest control (Tang et al. 2015).GNSS This technology facilitates the precise location of points, even in challenging environments such as forested areas, where traditional positioning systems encounter difficulties (Picchio, 2024; Zimbelman and Keefe 2018). However, numerous challenges arise in the context of positioning in forested areas, particularly in the presence of multipath effects, where signals experience attenuation due to the complex topography of the tree canopy (Cho, 2023; Feng et al. 2021; Cho et al. 2022).

Whilst terrestrial measurement methods have been shown to provide more accurate results than other methods, the challenges associated with their implementation in wooded areas limit their effectiveness (Cho et al. 2022). The performance of GNSS-based positioning in forested environments is significantly impacted by environmental conditions and limitations inherent in the method. For instance, static GNSS measurements have been observed to reduce positioning performance by extending the integer ambiguity resolution time when signals are blocked or distorted (Gallo, 2013). Consequently, the development of fast and precise positioning techniques for forested areas remains a significant research priority.

Real-Time Kinematic (RTK) GNSS measurements are utilized extensively due to their capacity to deliver centimeter-level precision and immediate positioning. The CORS technique further augments this capacity, enabling high-accuracy positioning with a solitary receiver and obviating the necessity for multiple crews and GNSS receivers (Wells and Chung 2023). Nevertheless, when the conditions surrounding the measurement change (e.g., in forest areas), the accuracy offered by the CORS technique may not be consistently achieved (Brach et al. 2019). Uzodinma and Nwafor (2018) reported that GNSS measurements may be unreliable in dense canopies. The accuracy of the CORS technique is significantly affected by the propagation of low-power, high-frequency GNSS signals, and signals blocked by intervening tree canopies, which have been shown to have a substantial impact on positioning accuracy (Catania et al. 2020; Kim et al. 2023; Feng et al. 2021; Yan et al. 2021).

A large number of studies have been conducted with the objective of enhancing the precision of GNSS measurements in wooded areas. For instance, Brach (2022) conducted rapid static measurements at points constituting a 33-point network in a forested region, achieving accuracies of 1.38/1.29 m and 0.74/0.91 m using GIS and geodetic-class GNSS receivers, respectively. In a similar vein, Bakuła et al. (2015) evaluated the performance of rapid static measurement methods employing multiple GNSS receivers, utilizing a bespoke apparatus in forested environments, observing enhancements in accuracy from a few centimeters to meters. Moreover, Brach and Zasada (2014) employed extended antennas to mitigate multipath effects in forested environments (Karjalainen, 2023). Pirti et al. (2016) achieved an accuracy of 6.5 cm with the CORS measurement technique near forested areas, demonstrating the potential for high accuracy positioning even in challenging conditions (Abdi et al. 2022).

This study proposes a novel and practical measurement method that aims to determine point coordinates in forest areas within a time frame of 3-5 minutes. To this end, four points forming two lines were marked in areas with clear visibility around the forest, in the same direction as the point to be determined in the forest. CORS measurements were made at these four points, and their coordinates were obtained. Utilizing these coordinates, the coordinates of the points were determined as a post-process, without the necessity of making measurements at the point in the forest area (points T_1 and T_2).The motivation of this study is to determine the coordinates of the points to be located in the inner areas of the wooded areas close to the open areas in a short time, such as 3-5 minutes. This approach ensures the location is determined with an accuracy of a few centimeters, mitigating the multipath and signal blocking issues commonly encountered in GNSS measurements in such environments.

MATERIAL AND METHODS

GNSS surveys

The static GNSS measurement method is utilized for high-accuracy positioning, particularly in forested areas where environmental conditions are challenging. This method involves installing the GNSS receiver at the designated point and collecting data over an extended period, thereby enhancing signal quality and minimizing atmospheric effects and other error sources (Zimbelman and Keefe, 2018; Xin et al. 2018). The collected data are processed with post-processing techniques, with reference station data and precise ephemeris information being used to correct positioning errors and ensure the obtained coordinates offer higher accuracy compared to other GNSS measurement methods (Xu et al. 2021). The accuracy of measurement is contingent on the quality of the receiver employed, the duration of the measurement, and environmental factors. In forested areas, elements such as tree canopy can adversely affect signal transmission, necessitating the judicious selection of measurement points (Weaver et al. 2015; Geng et al. 2020). This method is of great significance for land measurement, construction projects, environmental monitoring, especially the management of forest resources (Yeh, 2025; Yang et al. 2022).

The rapid static measurement method is a technique that allows high-accuracy location acquisition with short-term observations based on GNSS technology (Alkan et al. 2015). It requires shorter observation times (usually 3-5 minutes) compared to traditional static measurement, which provides a great advantage, especially in applications with time constraints. The GNSS receiver gathers and archives satellite signals during the measurement period, and post-processing techniques ensure minimal location errors (Geng et al. 2020). This method has been employed in all domains where static measurement is utilized, and it is notable for its capacity to deliver reliable and precise location in a brief timeframe (Wu et al. 2019).

The CORS system has a wide range of uses as a reference network that provides high accuracy and reliability. This system, which consists of geographically distributed stations, continuously monitors GNSS signals and provides users with real-time or post-processed correction data (Dardanelli et al.

2022; Pehlivan et al. 2019). The CORS system has been shown to provide decimeter or sub-decimeter precision by minimizing factors that affect positioning accuracy, such as atmospheric delays and satellite signal errors (Pipitone, 2023; Wu et al. 2015). When integrated with real-time kinematic (RTK) technology and various differential correction methods, the CORS system plays a pivotal role, particularly in fields such as land surveying, civil engineering, environmental monitoring, and disaster management (Öğütcü, 2020; Tran et al. 2023). The wide area coverage it provides enables users to achieve high-accuracy location even at longer distances. However, it is most widely preferred in engineering and scientific research due to its data continuity and reliability (Yurdakul and Kalayci, 2022; Liu et al. 2019).

Description of the Experiment

This study proposes a methodology for the implementation of the positioning method in forest areas where GNSS signals are not suitable for multipath or signal blocking measurements, thus obviating the necessity for measurements in such areas. In this context, the location of a point (T_1) marked in the area close to the forest area border was determined by theoretical calculations, and the factors affecting the positioning accuracy were examined (Figure 1).

Initially, a suitable T_1 point was determined in the forest area where GNSS signals were found to be weak or completely blocked. In order to indirectly locate the T_1 point, two auxiliary points (1 and 2) were selected in the open area, with the aim of ensuring that precise measurements could be made with GNSS, and that the T_1 point could be seen directly. Subsequently, auxiliary points 3 and 4 were determined in the open area on the lines 1-T_1 and 2-T_1, respectively, thereby enabling more accurate calculations of T_1 coordinates.

Steps are followed to calculate the coordinates of point T_1 in the forested area.

- Based on the coordinates of points 1, 2, 3 and 4, the azimuth angles (1-3), (3-4) and (2-4) and the length "c" are calculated with the help of the second fundamental geodetic problem.
- Using the azimuth angles,
  α = (2-4) - (4-3), β = (3-4) - (1-3) and γ= 200 - (α + β) are calculated.
- The lengths a and b are computed using the sine theorem ($\frac{a}{Sin(\alpha)} = \frac{b}{Sin(\beta)} = \frac{c}{Sin(\gamma)}$)
  - The coordinates of point T_1 are calculated from points 3 and 4.
  - $Y_T = Y_3$ + a*Sin (1-3) = Y_4 + b*Sin (2-4)
  - $X_T = X_3$ + a*Cos (1-3) = X_4 + b*Cos (2-4)

As GNSS measurement could not be performed at the T_1 point, it was observed that the accuracy of the obtained coordinates, which were determined by theoretical calculations, depended on two factors. Firstly, the proximity of points 3 and 4 to the lines 1-T_1 and 2-T_1 was a determining factor, and secondly, the magnitude of the γ angle (Figure 2).

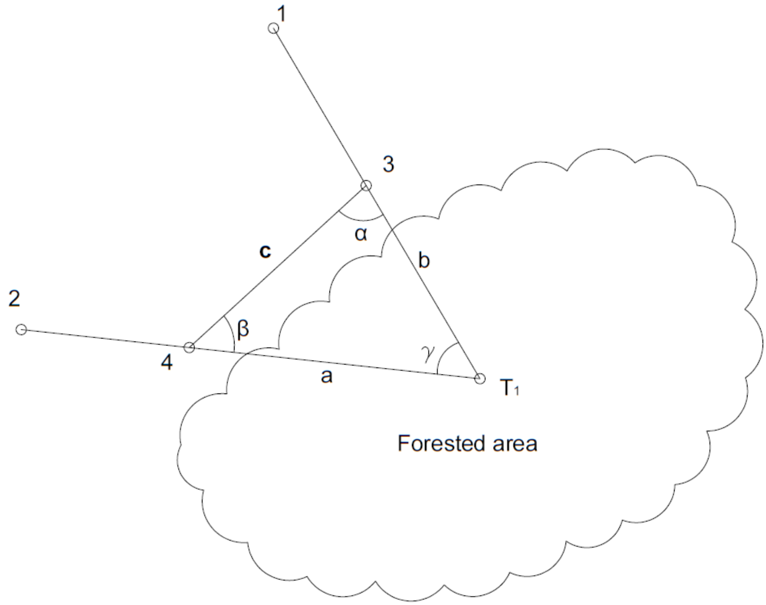

Figure 1: Network design for determining the location of point T_1

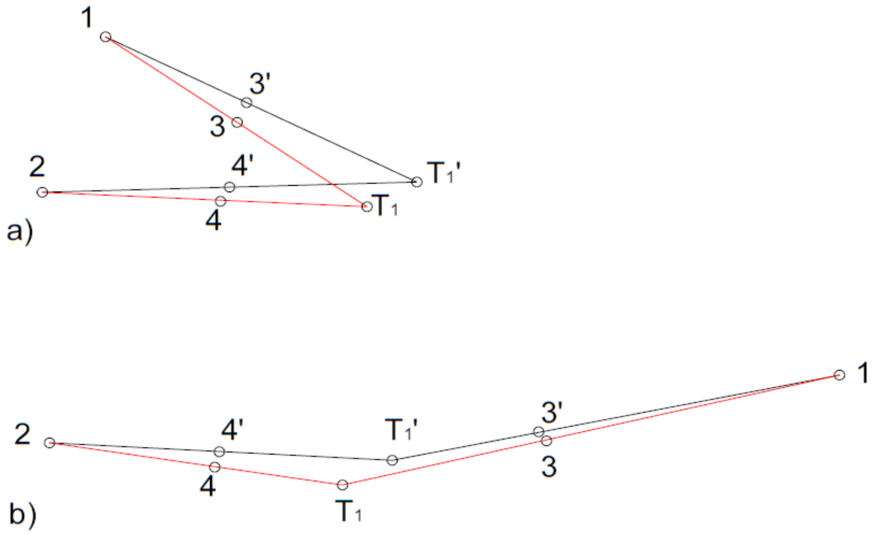

Figure 2: Plot of the change of position of the theoretical position T_1 and the realized pointT_1' around small (a) and 200g (b) values of the γ angle.

It was observed that when these points were positioned in close proximity to the measurement line, the calculated T_1 coordinates exhibited optimal accuracy, while as the deviations from the lines increased, the results exhibited a negative trend. Additionally, it was noted that if the γ angle was particularly small, approximately 200g (or around 180°), the calculated T_1 positioning accuracy underwent a decline. In the final stage, the T_1 coordinates were calculated theoretically, and the results were compared with different methods. Error analyses were also performed, with particular attention paid to the location of points 3 and 4 relative to the lines, the effect of different values of the γ angle, and comparisons with open area GNSS data.

These analyses were used to test the accuracy of the methods. The evaluation process concluded with the conclusion that this method, which is applied using auxiliary points in forest areas where GNSS signals are weakened or blocked, is a practical alternative that provides sufficient positioning accuracy.

Experiments

The experiment was conducted in two distinct wooded areas within the Davutpaşa Campus of Yıldız Technical University. This study investigates a practical solution that aims to overcome the positioning problem that occurs in forested/wooded areas close to open areas. In order to test the accuracy of this solution, measurements made at two different angle values (γ1, γ2) were examined, and the problems that may be encountered during the positioning process were evaluated. The tests were carried out in an area without difficult terrain conditions (within the university campus area). However, since forested areas are generally regions where the slope changes rapidly and have more difficult conditions, the validity of the proposed method in such environments is planned as a separate study subject in the future. In the selection of points, meticulous attention was paid to ensuring the presence of two distinct geometry test sites characterized by a small γ angle (see Figure 3) and an approximate mass of 100g (see Figure 4).

Initially, on 3 October 2023, points P1 and P2 were established in the vicinity of the primary test site, while points P5 and P6 were positioned in the proximity of the secondary test site. GNSS measurements were conducted in static measurement mode at these points, and coordinates were derived based on the measurements obtained over duration of two hours. The GNSS measurements were performed using four Topcon HiPer SR GNSS receivers. The technical specifications of the device utilized include a sensitivity of 3 mm + 0.5 ppm for horizontal accuracy and 5 mm + 0.5 ppm for vertical accuracy in rapid static measurement mode (L1 + L2). On 19 October 2023, the GEOMAX ZOOM 30 (2 mm + 2 ppm) total station was utilized to measure the horizontal and vertical angles and inclined distances of all points (including T_1 and T_2) in the study area.

The coordinates obtained from measurements made based on points in the region close to the study area were used as reference data in testing other measurements. Concurrently, RTK measurements were conducted utilizing the ISKI-CORS system, employing the PALA reference point, thereby acquiring the coordinates.

On 20 October 2023, a series of geodetic observations were conducted as part of a comprehensive research program. These observations included five-minute rapid static measurements, utilizing the ISKI-CORS system, which were performed in an open area. Concurrently, two-hour static measurements were conducted at the T_1 point in the primary test area. The purpose of these measurements was to assess the compatibility of the static GNSS measurement method by comparing it with the coordinates obtained through the conventional terrestrial measurement method.

Figure 3: Map of the first study area (small angle with γ ≈ 20g)

Figure 4: Map of the second test area with an angle value of approximately 100g (105g in the study).

For all GNSS measurements (static/rapid static), the data recording interval was set at 1 second and the elevation mask was utilized as 7.5°. The evaluation of static and rapid static GNSS data was conducted using Topcon Magnet Tools 8.1.0 commercial software, and precise positioning was achieved through the utilization of precision ephemeris and Final IGS products. The objective of this experiment was to compare the accuracy of different measurement techniques and to analyses methods to enhance positioning accuracy in forest areas. The experiments were conducted in selected forest areas in the Davutpaşa Campus region of Yıldız Technical University. Two different geometries were selected for this purpose, where the angle (ɣ) was small (Figure 3) and around 100g (Figure 4). Initially, on 3 October 2023, points P1 and P2 were established in proximity to test site 1, while P5 and P6 were established in proximity to test site 2. GNSS measurements were then performed on these points in static measurement mode for duration of 2 hours, after which their coordinates were calculated

The measurements were taken with four Topcon HiPer SR (Rapid-static (L1 + L2) H: 3 mm + 0.5 ppm and V: 5 mm + 0.5 ppm) GNSS receivers. On 19 October 2023, the horizontal angles, vertical angles and slant distances of all points within the designated study area (including T_1 and T_2 points within the wooded area) were measured using a GEOMAX ZOOM 30 (2 mm + 2 ppm) total.

RESULTS AND DISCUSSION

In this study, the PALA station of the ISKI-CORS network was evaluated as a reference for processing both static and rapid static measurements. The processing and adjustment of GNSS data were carried out with the Topcon Magnet Tools 8.1.0 commercial software. On the other hand, the coordinates obtained from the RTK measurements were recorded to the mobile receiver unit based on the PALA reference point of the ISKI-CORS network.

The coordinates obtained through the total station measurement method were selected as the reference, and it was determined that the coordinates obtained from each measurement method were close to the reference data with an accuracy of cm (see Tables 1 and 2).With the exception of the T_1 and T_2 points, all other points had different coordinate values despite having a clear field of view, and these coordinate differences are due to the accuracy of each measurement method and measurement device.

The obtained results demonstrate that the static measurement method yielded the most compatible results with reference data, and that the method with the largest differences was the CORS technique. In the context of forest studies, it is generally accepted that calculating coordinates to an accuracy of 10-15 cm is sufficient for forest measurement (Pirti and Kurtulgu, 2023). The differences between the coordinate data obtained from the reference method and the theoretically calculated point coordinates were found to be 15 cm for station T_1 and 10 cm for station T_2. While the error was calculated higher due to the small angle of the T_1 point in the first test area, better results were obtained at the T_2 point in the second test area, which was closer to the right angle.

Table 1: Differences of the coordinate values obtained by each measurement method from the reference coordinate values for the first test area.

Sts tions	Total station-CORS		Total station-Statik		Total station-Rapid static	
ID	Δy (m)	Δx (m)	Δy (m)	Δx (m)	Δy (m)	Δx (m)
1	0.026	-0.002	0.007	0.000	-0.004	0.007
2	0.017	-0.008	0.001	0.005	-0.001	0.015
3	0.027	-0.008	0.008	-0.006	-0.002	0.003
4	0.024	-0.012	0.008	-0.004	-0.002	0.000
T_1			0.025	0.018		

Table 2: Differences of the coordinate values obtained by each measurement method from the reference coordinate values for the second test area

Stations	Total station-CORS		Total station-Rapid static	
ID	Δy (m)	Δx (m)	Δy (m)	Δx (m)
5	0.016	-0.006	-0.002	0.005
6	0.011	-0.009	-0.001	0.009
7	0.015	-0.004	-0.001	0.002
8	0.018	0.006	-0.001	0.000

Table 3: The execution times of the measurement studies carried out in the first test area.

Name of The Work Done	**Time (s)**
Points establishment and direction aligned	15-20
CORS measurements	3-5
Static Measurements	240
Rapid Static Measurements	25-30
Terrestrial Measurements	45

Tables 3 and 4 present the times required for obtaining all measurements. The shortest times required for the location determination process, including the establishment of the point (fix operation in each method), are exhibited in the proposed method. Although the static measurement method provides similar results, the fact that the data evaluation phase, precise ephemeris and the final IGS product require more than 2 weeks demonstrates the effectiveness of the proposed method. The GNSS positioning accuracy varies according to tree leaf type, with the minimum position error being higher than expected (12.13 m). This indicates the effect of cover type on GNSS signal propagation (Feng et al. 2021). Given that the measurement accuracy used for forest studies is about 10-15 cm, it is evident that the proposed method is a practical, sufficiently accurate and faster method.

Table 4: The execution times of the measurement studies carried out in the second test area.

Name of The Work Done	Time (s)
Points establishment and direction aligned	15-20
CORS measurements	3-5
Static Measurements	120 (only P5 and P6 points)
Rapid Static Measurements	25-30
Terrestrial Measurements	45

More precise and accurate positioning is obtained from total station measurements. However, while the use of the GNSS RTK device requires one operator, other methods require at least two people (Lovrinčević et al., 2024). While the accuracy of RTK measurements decreases depending on the multipath effect of the measurement environment and the blocking of the signal, measurement times increase. Safrel et al. (2018) obtained coordinate data with a measurement time of approximately 40 minutes and an approach of over 10 m in their study. Pırtı and Kurtulgu, (2023) achieved 10-15 cm accuracy levels in the horizontal component in characterized forest areas. Measurements with Total Station can take several hours depending on the complexity of the work to be done and the desired accuracy level (Mihelič et al., 2022; Cho et al., 2023). However, in the current study, point positioning can be achieved with an accuracy of 10-15 cm in 20-25 minutes. When other studies are taken into account, it is clear that it is a very practical solution with more accurate point positioning in a shorter time. Brach and Zasada (2014) obtained coordinates with an accuracy of up to 25 cm depending on the antenna length in their study with an extended antenna.

CONCLUSIONS

The aim of this paper provides a comparison of different GNSS measurement techniques in terms of their accuracy and applicability in the forest areas. Firstly, the location of points T_1 and T_2 in forest environments is determined by using auxiliary points in open areas. Then, different measurement techniques and methods are tested, including static GNSS, rapid-static GNSS and CORS-based positioning. Finally, the results of these techniques are compared with the reference data obtained from total station measurements. The outcomes demonstrate that static GNSS measurements provide optimal accuracy, exhibiting the smallest coordinate differences compared to the reference data. Rapid-static measurements also yielded satisfactory results, substantiating their viability as a viable alternative in scenarios where time constraints exist. Conversely, CORS-based positioning exhibited the maximum coordinate deviations. All GNSS-based methods attain coordinate accuracy within a range of 10-15 cm, which falls within the acceptable limit for forest measurements.

The positional accuracy of the T_1 and T_2 points indicates that the geometrical configuration of auxiliary points plays a pivotal role in determining location accuracy. In the initial test area, where the γ angle is minimal, larger discrepancies were observed at point T_1 (approximately 15 cm). Conversely, in the subsequent test area, where the γ angle approaches a right angle, point T_2 exhibited enhanced accuracy (approximately 10 cm). This finding underscores the pivotal role of the placement and geometry of auxiliary points in determining the ultimate positioning accuracy. In all static GNSS measurements, the Topcon Magnet Tools 8.1.0 commercial software was processed using the precision ephemeris and final IGS products to enhance precision. A comparison of the results reveals that static GNSS measurements exhibit superior precision, while the rapid-static technique provides a balanced trade-off between accuracy and efficiency.

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